7. ALL THINGS CONSIDERED

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So much was promised but it appears that the light and the strong don't bring all that was hoped for. Certain properties are advantageous, others can be dealt with in particular way - may be. A number of properties pose serious problems - even safety risks - due to poor damage tolerance. Special measures have to be taken to try to compensate for these shortcomings, such at the expense of considerable weight. One can argue that with all-composite aircraft in the end 'similar safety means similar weight' when compared with aluminum aircraft - or not? There isn't really much that can be done to improve on composite's famously low impact performance - with all-composite aircraft the *windows provide better impact performance than the plastic skin. When struck by lighting one can only hope for the best - that the thickness of the skin at the fuel tank is sufficient to avoid transient hot spots - that all electric circuits and electronics are properly shielded - that continuity of the metal network is not interrupted - that that all 350,000 fasteners are spark free fit and properly encapsulated none damaged - that the inserted metal wire mesh and foil are completely intact and do provide electrical continuity for the lightning current - and of course that the inerting system is not out of order at precisely that moment. Crashworthiness has to be awaited but it is probably much more difficult to escape from an all-composite aircraft - that is when one survives the crash and the aircraft doesn't catch fire. Composites add fuel to the flames and keep burning for awful long time with the formation of thick hazardous smoke - oxidation of the carbon fibres results in the release of large amounts of highly contaminated respirable fibrils that clog the lungs and might even result in cancer long after the crash. Plain composites are not suitable - what the industry needs are aviation composites that do not pose all these problems - and these are readily available.*

With all-composite aircraft the main drive is to save on fuel. Boeing claims that the 787 will drop fuel costs with 20% compared to similar conventional aircraft 2) and Airbus claims the A350 to be again more fuel-efficient than the 787 3). This fuel efficiency is obtained, roughly half through improvement of the power houses also because of application of composites, and the other half through the aircraft's composite structure, again about evenly split over lower weight, improved aerodynamics and improved operation through more advanced systems - the 787 is to be a more electric plane 279). This means that when the intended weight reduction of 20% is not attained - at the moment it appears that no weight is saved at all - composites serve no purpose, since aluminium aircraft can also be provided with these powerhouses, better aerodynamics and improved operation including that more electric approach.

Weight watcher

It appears indeed to very difficult to achieve lower weight. Compared with traditional aluminium aircraft the A380, about 22% or 30 tonnes (~66,000 lbs) out of composite material was supposed to bring some 15 ton payload, but the target weight was initially exceeded by some 20 to 30 tons [312] but the engineers managed to bring that down to 5500 kg (~12,125 lbs) over the planned target weight and that will remain so [5]. Given the present problems with ramping up an increase in weight might be possible. The A400M - 35% out of composite including the wings - has yet to fly but is reported to be 12,000 kg (~26,450 lbs) overweight [6]. Also the 787, some 50% or 35 tonnes (~77,100 lbs) out of composite, has significant overweight - aiming for a weight reduction of 10.000 lbs (~4540 kg) Dreamliner One is reported to have gained 21,050 lbs (~9,550 kg) since firm configuration in 2005 [7] – first aircraft will be delivered at substantial over weight expected between 5000 lbs (~2270 kg) and 10,000 lbs (~4540 kg). Numerous redesigns are performed to lower weight - Boeing claims strongly reduced weight from Dreamliner 20 - but substantial overweight will remain - expected to be some 5000 lbs (~2270 kg). The A350, more than 50% or some 30,000 kg (~66,000 lbs) out of composite, is close to design freeze - target weight has already been increased twice with 3000 kg (~8035 lbs) - the plane is reported to be still some 8000 kg (~17,600 lbs) [8].

Comparison with traditional aluminium aircraft is, however, not completely objective - even when adapted to 787 standards with state of the art powerhouses and so on. An objective comparison requires that composed aircraft are considered - the next generation of civil aircraft - for which the A380 is paving the way. Composed aircraft have a hybrid structure - say roughly one third out of composites, one third out of other advanced materials and about one third out of traditional materials. New alloys are now available that are lighter, stronger and more corrosion resistant than traditional aluminium. With it, new production techniques have evolved, including super plastic forming, laser and friction welding, automated riveting and high speed numerically controlled machining and so on - and automation is progressing fast. Another most important development involves reinforcement of composites with thin layers of aluminium sandwiched between the layers of the composite - aluminum reinforced composites - in a way essentially similar to reinforced concrete.

It is against these developments that all-composite aircraft have to be compared and than it will show that composed aircraft are really lighter, that these construction materials provide real intrinsic safety with regard to impact and lighting strike and flammability - that design and modelling and manufacturing and inspection and repair are really much simpler - that operation will be really more efficient - and that these materials are readily available.

Also cars can be built from composites

Also cars can be built from composites - easier than aeroplanes and the pro and cons are even more in favour with cars - but somehow plastic did not make it in the car industry so far, most noticeably not in Japan. Car manufacturers have apparently good reason to decline on all-composite cars.

Composites have been used in the automotive industry since the 1950's, but steel is still the construction material of choice - although structural composites are nowadays widely used for such items as bumpers and panels 216) 217) - essentially light parts that can be easily exchanged when damaged. Many of the arguments that apply for aircraft do also apply for cars, but manufacturing differs in that much larger quantities are required. Carbon fibres are still rather expensive, but the light and the strong could probably bring much larger saving on fuel than with aircraft and the automotive industry is under heavy pressure to reduce on CO_2.

It is however well known that car engineers do not like composites because of the many physical unknowns and the lack of proper test methods. Likewise aircraft, mathematical modelling is nowadays a principal tool with the design of cars where simulations are based on the well-known homogeneous and isotropic behaviour of metals. Reliable composite models require extremely long solution times to deal with the typical inhomogeneous structure and anisotropic behaviour - up to ten times longer than with metals - even when assumed values are adapted for the many unknowns, something that cannot be avoided, which means that results can be questioned. Another problem is jointing. That poses no problem with metal cars where the number of joints has been brought back to a minimum and the remaining welding is almost completely performed by robots. With composites welding technology is still at its infancy and jointing involves either adhesive bonding or fasteners. This needs less complicated tooling, but both techniques are still rather complicated. Adhesive bonding need thermal curing with autoclaving, on the other hand fasteners require drilling that can cause delamination. Titanium fasteners are required to avoid galvanic corrosion, but these are very expensive and add with cars only marginal way to savings on weight. Both techniques require overlap that adds to the weight. A main problem that is put forward by car engineers involves more complicated repair - although essentially far easier and less critical than with aircraft. Workshops are all around, but more extensive damage to larger one-piece parts would require more sophisticated repair and probably return to the manufacturer.

Safety

Also likewise aircraft, safety is a most important marketing issue with cars but concentrates here in particular on crashworthiness. It has been demonstrated that very good crashworthiness can be obtained with composite frames, but this requires the assembly of additional energy absorbing materials, such that a collapsible structure is obtained and this adds significant to the weight and even more to the costs. Moreover testing of crashworthiness - well known by now with metal cars but still a big unknown with composites - is very complicated and hence very costly with composites. This means that engineers have to rely heavily on modelling for which sophisticated programs are in place, but these are based on metal. With composites accurate modelling is restricted for reasons cited before. Related to crashworthiness are composite's scattered breakage behaviour and its toxic flammability. Within the automotive industry this is regarded a serious safety risk in that passengers and persons hit by the car can get hurt by sharp edges and that in case of fire it becomes much more difficult to evacuate in time - and than there is this toxic flammability most unpleasant for persons in and outside the car, in particular in urban areas - all regarded far too problematic with marketing. Special measures have to be taken that involve extra protection of the fuel tank and additional air bags are even thought to be necessary along the outside of the car as well as other protection for sharp broken edges and corners, all adding to the weight.

Together these arguments have led the automotive industry to remain conservative on composites. Likewise aircraft, large-scale application of composites requires that special measures have to be taken to maintain safety standards - to an extend that savings on weight vaporize. It has, however, been found that best results including significant weight reduction can be obtained through selective application of composites, which has also been shown to be effective with the A380 - although the gain in weight was less than half of what was aimed for, other important features prevailed - most noticeably very good damage tolerance.

Aluminum ain't dead yet...

Aluminium aircraft have served us well and have set the standards to which new developments must be judged, in particular the unprecedented safety record that has been attained. Boeing's reasoning 'with aluminium, we were running out of ideas to do it better' [224)]*is myopic - to say at least - others see still great opportunities.*

With modern civil aircraft, aluminum comprises about 80 percent of the aircraft's weight, with the Space Shuttle even 90%. In particular its high strength and lightness, combined with its ability to absorb kinetic energy makes aluminum eminently suitable for aircraft construction. Agreed, corrosion poses a main problem with aluminium - and metals in general - and represents a huge economic impact. With aluminum aircraft different types of corrosion have to be considered - stress, galvanic, fretting, intergranular and son on. Aluminium fuel tanks are also susceptible due to the presence and growth of microbacacteria at the water and the fuel interface. On the other hand, aluminum does not absorb water and - apart form corrosion - is much less affected by environmental exposure than composites. Aluminum may be not so strong than composites and deform earlier due to stress but the material has proved to be strong enough and broad damage tolerance comes for free - contrary to composites aluminium presents a high level of energy absorption, no hidden damage, electrical continuity and is not flammable.

New aluminium alloys are being developed – providing pros and cons. Aluminum lithium alloys are some 5% lighter and about 10% stronger (static) - but also five times more expensive compared with the standard 2024/2524 and manufacturing shops remain reluctant to work with aluminium lithium because of the environmental threat they provide. A significant weakness of aluminium lithium remains it's low strain to failure and brittleness, which makes it sensitive to impact damage. If designed for similar robustness - i.e. impact resistance - as provided by the well-known copper aluminium alloys, there is the risk that the density advantage of aluminium lithium vanishes and just the high costs remains. These alloys are being further developed to improve on corrosion resistance and toughness but results have to be awaited. Titanium is expense but light and provides very high strength to weight ratio and high corrosion resistance, and is nowadays increasingly used in aircraft, typically some 10% by weight.

Manufacturing

Also manufacturing techniques are constantly improved making metal structures more competitive with aircraft. New technologies are emerging for extrusions in plates in aluminum-lithium alloys. *'These alloys have lower density, good and often higher strength than conventional aluminum alloys, and provide higher modulus, and therefore, enable weight savings. The trick is that you have to be very cautious in design so that you are using them in a way that make economic sense'* 64) according a Boeing engineer in 2007 *'this is not a technology push; it's a business proposition. It has to buy its way on to the aircraft'* 64). Airbus engineers are in agreement with Boeing in '*that the latest generation aluminium-lithium alloys offered many of the performance advantages which people had been looking to composites for' and* allowed for *'new seamless processes (quite literally) such as laser welding and friction-stir welding - instead of conventional riveting. Moreover, not only do the lack rivets and mechanical joins eliminate areas of high local stress, but it also eliminates 'nooks and cranny's' where moisture ingress would otherwise occur. The result: At a stroke a greater resistance to fatigue (no stress raisers) and corrosion (no moisture ingress). That's quite ironic really, especially given that fatigue and corrosion resistance are two principle selling points for using composite instead of aluminium.......yet more ironic is that even structures which are purportedly 'all-composite,' quite often have conventional metallic fasteners lurking in there somewhere - which of course would make the part susceptible fatigue, and thus require routine preventative inspection. And then when one also adds into the equation that the new Al-Li materials are lighter and stronger than previously, then all of a sudden one can see that aluminium ain't as dead as some folks might have us* *believe. Far from it'* (65) - with this last conclusion we couldn't agree more, but the section above needs some scrutiny. So are low impact resistance and costs missing in the Al-Li discussion. Single load path structures have lower design allowables than multiple load path structures and are therefore heavier. Furthermore welding may be not such good idea because this leads to integral structures, i.e. single load path structures. Note in this respect that Al-Li is the worst weldable aluminium, an option for welding is AlMgSc. The key to success is a metal bonded structure, as will be discussed later.

Aviation composites

From the foregoing discussion it appears that monolithic aluminium is still to be preferred over plain composites for the construction of externally exposed primary parts of civil aircraft because of low damage tolerance. With regard to new developments, application of aluminium-lithium offers limited advantages but the introduction of aluminum reinforced composites seems to be most promising - offering true aviation composites to be preferred over monolithic aluminium and plain composites.

Composite are reinforced with thin aluminum sheets that are bonded between layers of glass fibre reinforced prepregs. No new materials are required in order to increase the structural capability significantly - the new composition delivers the high performance. Key to success is the consequent integration of material properties and design features. These provide both a multiple load path material and a multiple load path structure (218) *- hence higher strength - leading to high design tolerables and consequently to low weight structures and aluminium reinforced composites offer many other interesting features.*

Industrial aluminium reinforced composites include *Arall* where aluminium layers are bonded together by aramid fibre composite, *Glare* where the composite contains glass fibres and *Central* that represents another breakthrough in this field and consists out of thicker aluminium laminates strongly bonded between layers of *Glare*. Other developments in this field involve - amongst others - titanium sheets, carbon fibres and thermoplastic polymers [219)]. Research is still ongoing - and will undoubtedly lead to further exiting discoveries and developments. Aluminum reinforced composites can be tailored - more so than plain composites to the load [380)] - to suit a wide variety of applications through adaptation of the architecture that includes next to fiber/resin system and optimum fiber orientation features typical with aluminum reinforced composites - different stacking sequences and layer thicknesses, improved aluminum and resin and fibre properties that lead to different grades of aluminium reinforced composites – and the thickness of both the composite and aluminium layers can be carried. Aluminum reinforced composites are typically cured at 120 C, but it is possible to adapt a resin and aluminium that allow for higher curing temperatures with proportional increase of the glass transition temperature. Production of very large panel faces is possible through slicing technology that will be explained later. Doublers that provide local reinforcements can be integrated into the panel during lay-up. Furthermore one can envisage that at least part of the aluminium laminates are perforated which saves on weight but does not have to affect either in the plane nor through the thickness performance - because it is possible to connect composite layers through the aluminium layers by means of matrix contact, adhesives, stitching or otherwise performance both in the plane trough the thickness can be improved. The outside layers can be non perforated and perforation of the inner layers can be designed according physical load pattern.

Glare

Developed during the 1990's [220)] *- Glare is already applied for the upper and lateral fuselage of the A380. Although well researched* [180)] *this is an extreme first application of a completely new material straight form the university laboratory. The A380 fuselage is an enormous pressure vessel that has never been tried at this size. But Airbus was in desperate need for any pound that could be saved and the* *application is a success - Glare brought some 800 kg - the material performs well but is not considered for the A350, something that might chance.*

Glare consists out of thin, 0.2 to 0.4 mm sheets of aluminium alloy bonded by glass fibre reinforced prepeg adhesive, around 0.2 mm thick. It is heavier than fibre reinforced epoxy composite but still some 10% lighter than aluminium. Glare does not have the static strength and stiffness of unidirectional carbon fibre composites, but for a fuselage skin application these properties are no major design parameter and therefore they are of minor importance. The design philosophy for aluminum reinforced composites structures, as defined by Airbus, is targeting a structure that does not require any scheduled fatigue inspection. With an outstanding technical record, this target has been achieved with the A380 220). The manufacturing philosophy to lay-up the desired laminate in a mould with all design details involved, thus to avoid a lot of the classical manufacturing steps required for aluminium alloys - milling, stretch forming, doubler attachment and so on - complemented by the invention of the splice technology that allows to manufacture very large panels, moved the system costs into the attractive range. Manufacturing has proven to be simple, yet a significant portion of labour is involved but options for automation can be easily identified.

With aircraft, the optimum choice to obtain both low weight and increased robustness for an attractive price is obviously aluminium reinforcement of composites - as proven for applications such as fuselage skin panels. Peculiar is the observation that Alcoa, who owns a substantial portion of the related patents, is not producing the aluminium foils needed for Glare. And this is bound to chance as well.

Central 220)

The same university that developed Glare announced in 2007 a new material - Central 221) *- invented by a small company in the Netherlands - GTM - together with Alcoa. Central is essentially a unique through development of Glare that now* *combines 1 to 4 mm thick laminated aluminium and Glare layers, sandwiched together through a new high strength glass fibre prepeg. Extremely strong bonding between the thick aluminium sheets and Glare is achieved with a new adhesive Bondpreg®. This allows for commercial production of thicker sheets - without increasing the number of layers - required for aircraft wing structures. Researcher found 'Superior fatigue crack grow properties, high strength and strait forward manufacturing for thick material at much lower cost'* 220) 221).

Central is here regarded a most important development - according the U.S. Air Force *'a promising concept'* 226) - that will compare much better, if not superior, with plain aluminium lithium and plain composites when applied in aircraft, with Glare to be the preferred choice for thinner applications. From the manufacturing point of view, however, the Central concept seems to be a challenge compared with the simple aluminium reinforced composite solution - Glare - reminding that thicker sheets will not fit into the mould without pre-forming. A solution anticipated is that the thick itself forms the mould.

All things considered

Aluminum has been the construction material of choice for aircraft for over fifty years. The material is light and strong with good impact performance, offers perfect lighting strike resistance, very good crashworthiness and is not flammable - corrosion is however a main problem but this has not hindered that traditional aluminum aircraft now present unprecedented safety in civil transport. Composites are stronger and lighter but pose so many shortcomings that have to be compensated for - listed before - this at the expense of virtually all weight that was meant to be saved and even than damage tolerance and hence safety remain a serious concern, with the situation expected to become even worse when aircraft are longer in service due to ageing and repair. Aluminum reinforced composites make a much better choice to be preferred over both monolithic aluminium and plain composites - these *materials exploit the advantages of plain composites and monolithic aluminium, discount the disadvantages* [380)] *and offer many other unique features - providing real aviation composites with excellent fatigue and a high level of damage tolerance* [372)].

Aluminum reinforced composites have been extensively researched - Glare in particular [180) 374) 375)]. Metal reinforced composites behave more like a metal structure - rather than plain composite - provide lower weight and improved fatigue strength as well as very good impact performance, good lighting strike resistance, excellent corrosion resistance, good crashworthiness, are essentially not flammable and present many other important features - damage tolerance is excellent and has not to be build into the structure through special measures likewise with plain composites - and allows essentially for a damage tolerant design approach consistent with how metallic airframe structures are currently designed [373) 380)].

Crack bridging - Insidious damage does not pose problems likewise plain composites in that aluminium reinforced composites are less prone to manufacturing defects - also delamination during service does have less profound effect. One can argue that with aluminium reinforced composites hidden damage does not pose a safety risk - at least to a far lesser extent than with to plain composites - because aluminum reinforced composites show excellent crack growth characteristics. The major mechanisms are crack initiation and propagation in the metal layers and delamination growth in the wake of these cracks at the interfaces with the intact fibre layers. The very nature of Glare is it crack bridging [380)] - the fatigue insensitive fibres restrain the crack opening and transfer - bridge - load over the crack into the metal layers [376)]. Crack propagation life is therefore significantly longer than with monolithic aluminium. Crack grow rates are actually ten to hundred times slower than with monolithic aluminium - which explains the very good fatigue strength. Fatigue strength is however seriously affected at higher temperatures - from 80 C [180)] - because of increase in crack grow rate. Note that Glare is cured at a temperature of 120 °C and has a glass transition temperature at dry condition of about 100 °C.

Mechanical and thermal continuity - Contrary to plain composites, thermal behaviour and stress strain behaviour is more near to that of plain aluminium - aluminum reinforced composites provide therefore both mechanical and thermal continuity while heat is better conducted - this limits internal stresses when such materials are combined within the airframe. The same applies for residual stress, stress redistribution at fastener points and vibration and damping behaviour.

Residual stress - Post-stretching is a potential method to change the unfavourable residual stress system in fibre metal laminates - essentially in a way concrete is pre stressed. During post-stretching of the material, the metal layers will be strained into the plastic region of the stress-strain curve, while the fibre layers remain elastic. After unloading, the residual stress system will be reduced or even reversed dependent on the amount of stretching 371).

Impact performance - Impact resistance of aluminium reinforced composites is related to the aluminium and glass/epoxy properties and the rather rigid structure that is obtained with this combination - and is significantly higher than the impact resistance of monolithic aluminium - the post-impact fatigue performance and residual strength outperform both a typical plain composites and monolithic aluminum.369). Contrary to plain composites, impact does not cause large areas of internal damage - internal impact damage is mostly confined to a relatively small area in the direct vicinity of the point of impact and is normally easy to repair 379).

Splicing concept - With aluminium reinforces composites, both single and double curved panels can be produced in a single operation cycle. The construction of larger elements has been made possible by the development of the so-called *splicing concept* 382). A spliced laminate is built up within the same laminate layer by putting metal sheets against each other along a splicing line. To avoid localized lack of strength or stress concentrations splice lines are alternated through the thickness. Although the splicing concept represents an effective technique to build large panels, splice lines constitute discontinuities, which can lead to severe stress concentrations and delamination, if they are not carefully designed.

Electrical continuity - a most welcome feature with aluminum reinforced composites is the perfect electrical continuity that is provided by the aluminium layers - essentially comparable with monolithic aluminium. However, measures have to be taken at the splicing lines such that any discontinuity is avoided that might effect unhindered flow of electrical current - for example overlap is possible with slicing that also provides mechanical and thermal continuity. No doubt that aluminium reinforced composites produce an excellent Faraday cage - actually a multilayered cage.

Crashworthiness - Aluminum reinforced composites have significant energy absorbing capability - at least equal to monolithic aluminum - probably even better. Likewise monolithic aluminium the material does not shatter upon heavy collision experienced with crash conditions and consequently present excellent crashworthiness characteristics.

Flammability - When subjected to fire the outer aluminium layer will melt away whereas the other layers will remain intact due to carbonisation of the glass/epoxy layers and supported by delamination of the laminate. The air in the delaminations acts as insulation, keeping the temperatures at the non-exposed side relatively low 377) – depending of course on type and thickness and the intensity of the fire. Contrary to carbon fibre, glass fibre does not oxidize and consequently does not produce fibrils upon heating.

Moisture and temperature - Plain composites do not corrode likewise aluminium but they can absorb water, other fluids and gases. Combined cyclic mechanical and environmental loading together with high moisture concentration, high temperatures, corrosive fluids and ultraviolet radiation (UV) can affect the performance of plain composites during service as has been pointed out before. When it does this can strongly affects material properties. Aluminum reinforced composites on the one hand are less affected by ageing - but moisture can cause corrosion of the aluminum, affect the adhesive strength between the composite and the aluminum layers and can plasticize the matrix, on the other hand moisture absorption is severely hindered due to the protection provided by the aluminum layers. Moisture absorption increases with temperature that also generates stresses between the layers due to differing coefficients of expansion 375).

Corrosion - Corrosion is a main problem with monolithic aluminium, as was pointed out before. With aluminum reinforced composites corrosion attack is limited to the outer aluminium layers. A pleasant surprise was to find that the thin aluminium alloy sheets show significant better corrosion behaviour when compared with thicker sheet normally used in aircraft [373)]. The reason for this is that faster quench of the thin sheet after rolling results in less alloy elements at the crystal boundaries. Moreover, the aluminum sheets are anodized and coated with a corrosion-inhibiting primer prior to the bonding process. Not surprisingly, test results reveal that the effects of moisture and temperature are much less severe than with plain composites - and monolithic aluminium - no changes on mechanical properties (tensile and compression strength) were observed with aluminium reinforced composites when subjected to hygrothermal conditioning [378)]. Problems with *galvanic corrosion* are largely avoided.

Mathematical modelling - With aluminum reinforced composites stresses distribute more along straightforward loading paths - possibly in determistic way - the aluminum layer prevents multiple global longitudinal splits because the aluminium layers impede and arrest crack growth within the composite layer when subjected to cyclic loading - but failure mode is still rather complicated when compared to monolithic aluminium, however more predictable than with plain composites. This means that mathematical modelling can be performed with greater accuracy because it is easier to set boundary conditions than with plain composites [370)].

> With aluminium reinforced composites the typical affects that determine stress distribution in plain composite behaviour have not to be taken into account - at least pose less of a problem - like heterogeneous structure, amorphous state, anisotropic behaviour and to a lesser extend residual stress, stress redistribution and mechanical and thermal discontinuities - including intricate deformation behaviour and complex failure modes mentioned before - all of which are poorly understood when plain composites are subjected to the extreme conditions that apply to aircraft - and make proper modelling with plain composites so extremely difficult - if possible at all.

This brief discussion underlines that aluminium reinforced composites represent a most important material concept for highly durable lightweight design of externally exposed primary structural parts of aircraft and provide excellent damage tolerance - to a level far beyond that of aluminum civil aircraft.

Panel versus barrel revisited

Whether a barrel design or a panel construction is to be preferred for the construction of a composite fuselage has to be awaited - the panel design of the A350 is still on the drawing board - but it is clear that panels present greater flexibility and plain composites could be relative easily switched for aluminium reinforced composites - which is not possible with barrels. Although at a late stage in the project this offers a solution to many problems and is probably seriously considered by Airbus where at least some engineers must by now have come to the conclusion - stressed at these pages - that composites are just not suitable for the construction of outer skin of civil aircraft. A skin out of plain composites is just too vulnerable to impact and lighting strike and poses a serious threat to passengers and crew in case of crash landing certainly when the aircraft catches fire. Also inspection and repair pose still insurmountable problems. Given present state of the art technology there is essentially not so much that can be done to improve on these issues in substantial way. Measures that can be taken leave the aircraft at risk and eat away all possible savings on weight.

Engineers at Boeing and Airbus have learned that the strong and the light do not translate in saving on weight, that not much can be done about composites' poor damage tolerance and that and managers must by now have become aware that public opinion might oppose all-composite aircraft when this comes more in the open - and that this will happen sooner than later. Taking damage tolerance and related safety aspects of aluminium aircraft as benchmark it is now the choice between inferior all-composite aircraft and superior composed aircraft - taking weight of aluminum aircraft as benchmark it is a choice between no weight saving with plain composites and moderate weight gain with composed aircraft - taking inspection and repair of aluminium aircraft as benchmark it is a choice between huge cost overrun with all-composite aircraft and substantial cost saving with composed aircraft. Ample reason to reconsider the all-composite approach. Airbus is at the moment the only company in the world that has large-scale experience and expertise in this field - and engineers should now concentrate on the wings.